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A NOVEL TECHNIQUE FOR COMBINING CONVENTIONAL AND FLOW SPINNING WITH SIMULTANEOUSLY BURNISHING PROCESSES

K. M. ATIA[1], S. Z. EL-ABDEN[2], M. N. EL-SHEIKH[3] & W. W. MARZOUK[4]

[1]*Research Scholar, Department of Production Engineering and Mechanical Design, Minia University, Minia, Egypt*

[2]*Assistant Professor, Department of Production Engineering and Mechanical Design, Minia University, Minia, Egypt*

[3]*Professor, Department of Production Engineering, Minia University, Minia, Egypt*

[4]*Professor, Department of Production Engineering and Mechanical Design, Minia University, Minia, Egypt*

ABSTRACT

In this research, new Technique was developed to perform three different operations in the same stroke, namely conventional spinning, shear spinning (wall thickness reduction) and burnishing processes. Experimental work was conducted and confirmed the success of the presented technique. The response of the product quality and required load to process parameters such as rotational speed (46,76,150 and 230 rpm), axial feed (0.15,0.3,0.6 and 1.21 mm/rev), burnishing load (20, 25 and 30 KN), distances between shear balls, and distance between burnishing balls was checked and clarified. The results showed that, the optimum condition for forming load and surface roughness occurred at rotation speed at 150 rpm, axial feed 0.3 rev/mm and burnishing load 25 KN. The surface roughness of the new technique products has been found to be about 0.41 µm and the forming load not more than 6 KN at optimum case. When distance between the shear balls increases, the forming load decrease until it reaches its lowest level at 2 mm, and any further increase in this distance increases the process load. Hardness and surface roughness increase with an increase of the distance between shear balls. It can be also concluded that the hardness and forming load increases with the increase of space between burnishing balls. However, the surface roughness improves with increasing burnishing balls distance.

KEYWORDS: Combined Processes, Conventional Spinning, Shear Flow Forming, Ball Burnishing, Hardness & Surface Roughness

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Original Article

1. INTRODUCTION

Sheet metal spinning is the most forming procedure used widely for producing symmetrical parts and hollow circular cross-sections items [1,2]. The expression metal spinning relates to category of three processes: conventional spinning, shear spinning and tube spinning. In conventional spinning, a sheet blank is converted into a desired formation without a change in the thickness and with a measured decrease in diameter. Contrary to conventional spinning, in shear spinning, the item thickness is reduced [3]. On another hand, the burnishing process is a desirable finishing method which can enhance the metal surface hardness, surface finishing, and accuracy dimension. Also, the burnishing process decrease the surface wrinkle and adjust the microstructure [4]. Last two decades, the research in metal spinning and its parameters were the point of interest. The effects of the thickness of blank, mandrel, roller nose radius, rotation speeds, feed of the roller and over-roll thickness on the surface roughness of cone shape items was investigated by **Chen et al**. [5]. It was concluded that heavy over-roll combine with the thinner sheet blank, big roller nose radius and slower roller feed are useful for get smooth surface

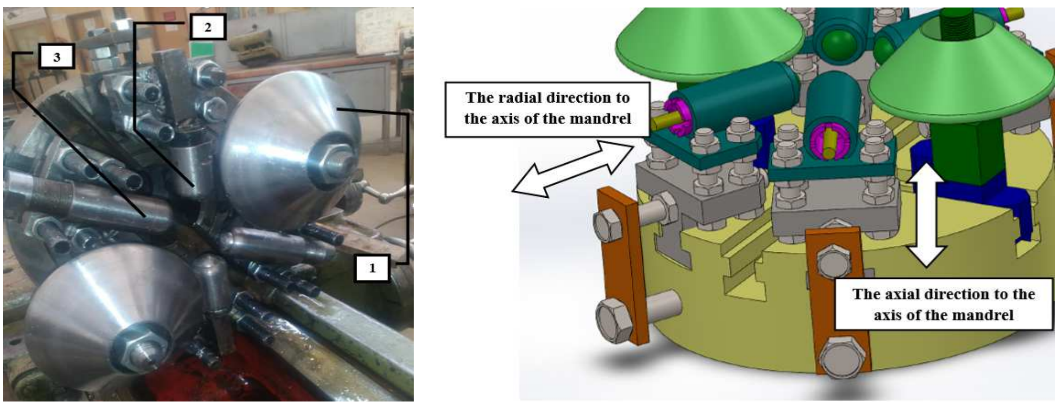
roughness. Over-roll of the blank in flow spinning is a successful way to decrease the surface roughness of the part. However, **Molladavoudi and Djavanroodi [6**]inspected the influence of thickness decrease on the mechanical properties and spinning accuracy on aluminum workpiece. The experimental results show that with an increase of thickness reduction the yield strength, ultimate tensile strength, and surface hardness increase, and on the other hand, it has opposite effect on diameter increase, accuracy of the tube, surface roughness, and elongation of tube. Moreover, the optimization process for multi-step non-circular sheet spinning with the target of decrease wrinkling and thinning was studied by **Härtel and Laue**[7]. The analysis showed that the smallest sheet thickness take place during a narrow band of the axial feed. To decrease thinning, the feed rate was increased, and the operating angle was fit within this narrow band. Using this process, it was achievable to reduce thinning from an initial 54% to 33%. In another research topic of material wrinkling failure mechanism of conventional spinning processes and the effects of material characteristic and process variables, **Watsonet al.**[8]. The author found that material wrinkling defect starts when a plastic hinge is created between the roller and the border of the blank. to add to that, both roller feed per pass and feed rate makes the most important effect on the starting of wrinkling defect, as they increase the bending stresses lead to a plastic hinge to take shape more quickly, thus wrinkling to happen very quickly. In addition, **Konget al.**[9] investigated the flange wrinkling in conventional spinning process. The results show that the lowering of the circumferential compressive stresses distributed in the flange due to by short feed ratio decrease the flange wrinkling. Moreover, **Wang and Long**[10] Investigated four different roller route shape to carry out spinning experiments this paths are linear, combined concave and convex, convex and concave. it can be concluded that the concave route cause excessive forming forces between these four roller path shapes. Applying the concave roller path leads to a cause of largest decrease of wall thickness of the part and applying the convex roller path assists to keep the initial thickness unchanged. A major curvature of the concave path would result in more decrease in wall thickness of the part. Furthermore, burnishing process and its parameters are highly affecting the process of metal spinning. Therefore, **Rodríguezet al.**[11]studied the effect of deep ball-burnishing using various variables for finishing spin items. The experimental results show that burnishing is an inexpensive and practical mechanical treatment for the characteristic enhancement of spin parts, not only in surface roughness but in compressive residual stresses also. In addition, the effect of burnishing force and number of roller passes on surface characteristic of mild steel specimens was investigated by **Raoet al.**[12]. This study shows the hardness of mild steel specimens enhances with increase in the burnishing force up to 42 Kgf., moreover, surface hardness decreases with the increase in burnishing force on specimens. The maximum surface hardness occurred is 70 HRB, the highest decreases in surface roughness is noticed in first five passes on specimens by roller burnishing process. However, **Basak and Goktas**[13] studied aluminum alloy burnished using various burnishing variables (rotation speeds, feed, number of passes, and pressure force) with burnishing equipment. This study shows that surface roughness decreases if the applied force increases. The greatest surface roughness has been obtained with 200 N force and 0.3 feed and rising of the number of revolutions enhances the surface roughness for the applied force of 100 and 200 N. the multi roller burnishing process on nonferrous metals in other words Aluminum, Brass and Copper to enhance surface roughness and surface hardness has been investigated by **Thamizhmaniiet al.**[14]. The surface roughness on different no-ferrous metals enhanced by increase of spindle speed with increase of feed rate and depth of roller. There are some parameters that should be taken into account in spinning process. One of this issue is influence of difference in perform heat treatment on the flow formability and mechanical properties of flow formed steel tubes. This topic studied by **Podderet al.**[15], They showed that microstructural characteristic like size and shape of secondary phase and strain hardening features of forming play a serious part in earning good flow formability in the steel. In addition**, Hanet al.**[16] studied the hot shear spinning of titanium alloy thin-walled shells under various load situation using the coupled thermal-

mechanical type. The results showed that elevated workpiece temperature and mandrel preheat temperature can get around a minimal temperature slope in the thickness direction, Also the deviation ratio has a complex effect on temperature variation of the deforming region and a noticeable negative effect on the gap between mandrel and the inner surface of the part. Furthermore, the friction between spun item and roller has an important effect on the temperature variation. Otherwise, **Shimizu and Tanaka**[17] studied the spinning of pyramidal-shaped workpiece in order to examine the applicability of the synchronous spinning method to further complex items. The results confirm the vantage of the synchronous spinning method in the condition of small quantity production. However, the result of ultrasonic vibration amplitude, static force and feed rate on surface characteristic of aluminum alloy was studied by **Teimouriet al.**[18]. They suggested that in order to obtains highest hardness and lowest surface roughness, the ultrasonic vibration amplitude of 8 µm, feed rate of 1000 mm/min and static force of 38 N, should be chosen. Furthermore, **Huanget al.**[19] studied the neck-spinning process of a tube at high temperature experimentally and numerically. Tension tests were carried out at a high temperature and different strain rates. It is observed that over the neck-spinning operation, the warp angle between the upper and lower of the rotate tube rises significantly as the coefficient of friction increases, the roundness of the part decreases as the roller speed increases. In the area using balls for flow forming spinning **Abdel-twab et al**[20] conducted a research on the ability of using balls to perform a reduction in a pipe wall thickness with inner rips creation, the proposed tool conducted the required wall thickness reduction and the inner rips too, Abdel-twab et al performed an examination into the effect of some process variables on the part quality and process required load, they reported the influence of mandrel rotational speed, feed rate, distances between balls, and the balls in feed on the product surface roughness and hardness beside the operation required load. **Saied et al**[21] suggested a new combined tool has the ability of performing conventional spinning with wall thickness reduction in one pass, they reported that the new proposed tool is successful in achieving the required cup with wall thinning in one pass.

The objective of this work is to design and manufacture combined spinning tool. This tool is capable of performing three different forming process simultaneously. These three processes are conventional spinning, flow spinning and burnishing process. as well as, study the influence of the process parameter like burnishing load, rotation speed, axial feed, distances between shear balls, and distance between burnishing balls.

2. EXPERIMENTAL WORK

2.1. New Combined Tool

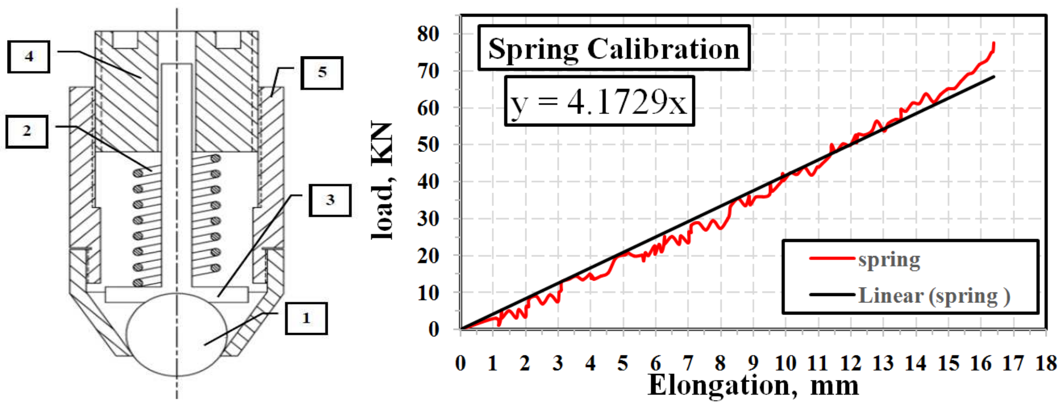


(a) **(b)**

Figure 1: (a) The Completely New Combined Tool. (1) The Rollers for Conventional Spinning (2) The Balls for Shear Spinning (3) The Balls for Burnishing Processes. (b) Motion Mechanism for Balls Holder.

The design of the tool for the proposed technique is shown in **Figure 1**. The tool consists of lathe chuck fitted with three different parts as follows:

- The two rollers performing the conventional spinning process. The assembly of the two rollers are mounted on two opposite jaws of separate lathe chuck with four independent jaws. The separate chuck service as a tool holder. This assembly makes the two rollers in the same level and the rollers are mounted on shafts with ball bearings to allow free rotation of the rollers to reduce friction during the forming process. The rollers can be moved inward or outward in radial direction of mandrel through the separate jaws of the chuck.
- The two balls which are performing the process of shear spinning have a diameter of 27 mm. The balls are installed on new keyways in the chuck which have machined by milling machine. This assembly makes the two balls in the same level following the rollers level by about 10 mm. The Mechanism as shown in the **Figure 1 (b)** allows the balls move inside and outside vertically on the mandrel axis and move the balls in a direction parallel to the axis of the mandrel. This mechanism can provide a different distance between balls.
- Two balls performing the burnishing process having the same diameter of shear balls. The two burnishing balls are mounted in the same way of balls of shear spinning process and have the same motion mechanism. **Figure 2** shows schematic representation for burnishing housing and the calibration curve for spring. This spring used to perform the various burnishing loads on workpiece by turn the lock nut to compress the spring. That will lead to increase in the ball load against the workpiece.



(a) **(b)**

Figure 2: (a) Schematic Representation for Burnishing Housing. (1) Ball 27 mm Diameter (2) Spring (3) Adapter (4) Lock Nut (5) Burnishing Tool Housing. (b) Spring Calibration Curve.

2.2. Principles of New Technique Tool

The principle of the developed technique is shown in **Figure 3**. The tool depends on the concept of carrying out the conventional spinning process by rollers followed by two first balls which will perform the wall thickness reduction and then the last two balls perform the burnishing process. The assembly of the tool is fed in the direction of the blank and mandrel. Firstly, the rollers contacts with the blank and start to perform the conventional spinning process. After 10 mm (the distance between the nose of the rollers and center of the first shear balls) the shear flow balls will start to touch the formed part of the blank to carry out the shear flow process with reducing the wall thickness. After 5 mm from center of shear flow forming balls the burnishing balls will start contact with the surface of formed part to carry out the burnishing operation.

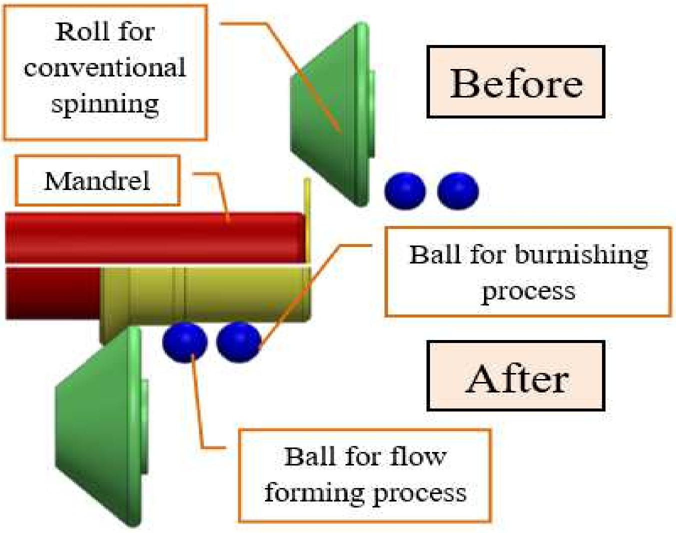


Figure 3: Principle of Developed Technique.

2.3. Experimental Setup

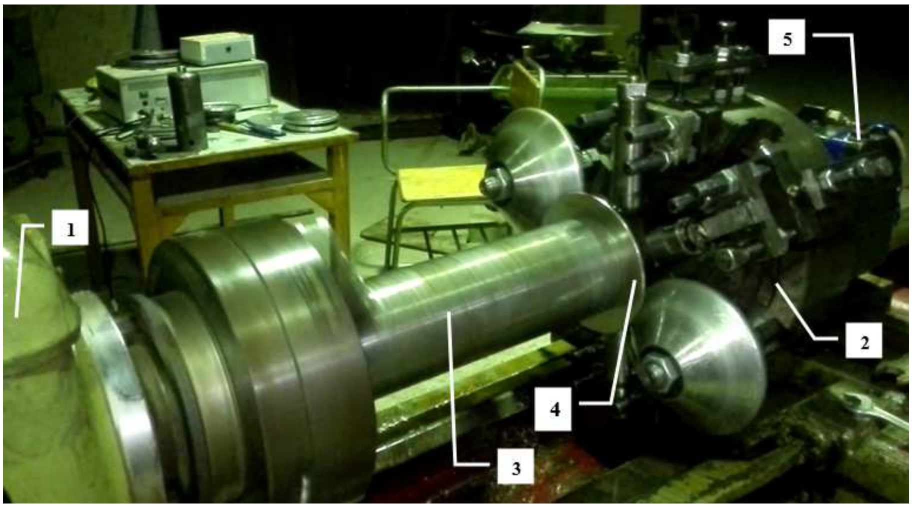


Figure 4: Experimental set-up of the Combined Process. (1) Center Lathe Machine (2) Combined New Tool (3) Mandrel (4) Aluminum Blank (5) Load Measurement Device.

The setup of the experimental work can be found in **Figure 4**. The apparatus consists of new tool (2) which is attached to the lathe carriage in order to use automatic feeding of carriage, the lathe machine (1), The mandrel with diameter of 105 mm (3) which is attached to the lathe chuck, and the blank (4) which is attached to the mandrel. The blank material was Aluminum as received with 155 mm diameter and the specimen was tested experimentally found to have yield strength of 66 MPa, strength coefficient of 141 MPa, and strain hardening exponent of 0.27with 37 HV Vickers hardness. It can be seen from **table 1** that the experimental variables have been examined.

Table 1: Experimental Chosen Parameters

Material	Aluminum
Mandrel speed (rpm)	46,76,150 and 230
Feed rate (mm/rev)	0.15,0.3,0.6 and 1.21
Burnishing load (KN)	20,25 and 30
Distance between shear balls (D_{SB}) (mm)	0,1,2 and 3
Distance between burnishing balls (D_{BB}) (mm)	0,1,2 and 3

Diameter of mandrel (mm)	105
Initial blank Diameter (mm)	155
Initial blank thickness (mm)	3
Thickness of formed specimen (mm)	1
Balls diameter (mm)	27
Spinning ratio	1.47

3. RESULTS AND DISCUSSIONS

3.1. Effect on Maximum Total Load

3.1.1. Effects of the Axial Feed

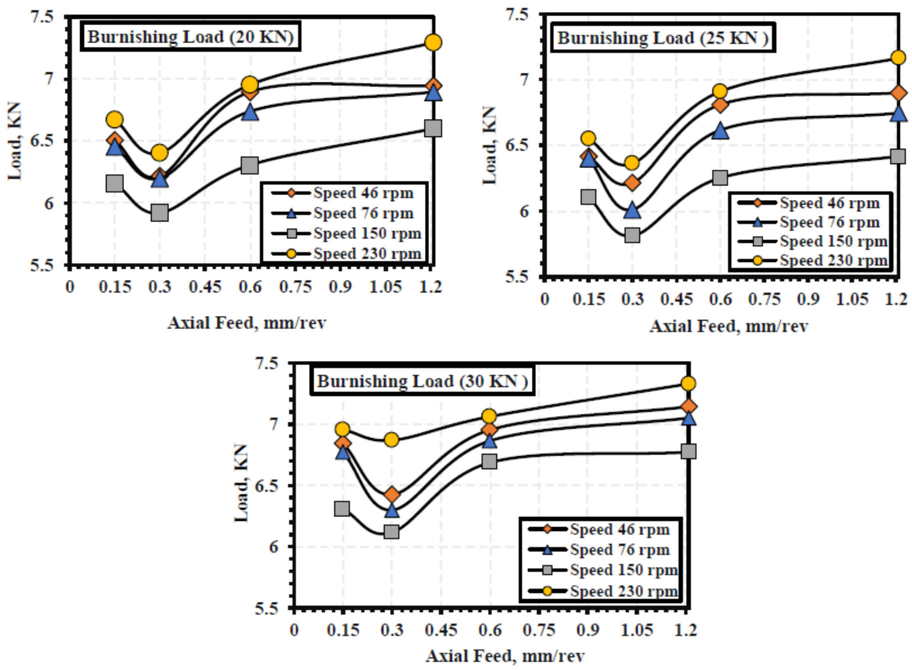


Figure 5: Relationships between Maximum Forming Load and Axial Feed under different Rotation Speeds.

The measured maximum forming total loads required for the combined process has been plotted versus the axial feed at different rotation speeds in **Figure 5**. It was found that the increase of axial feed decreases the maximum forming total load until it gets to its lowest level at the optimum axial feed of 0.3 (mm/rev). This is due to the agreement between this feed and the deformation rate of the material. The forming total load arises once more with the increase of the axial feed over its optimum value. This can be attributed to the increase in the strain hardening of the blank material in the forming operation. It can also be observed from **Figure 5** that at the rotation speed of 150 rpm, the maximum deformation load is at its minimum value relative to other rotation speeds. These results extend in the three different burnishing loads.

3.1.2. Effects of the Rotation Speed

The relations between rotation speed and maximum forming total load required for the proposed technique with various axial feeds can be found in **Figure 6**. It was noticed that the maximum deformation load decreases with the increase of rotation speed while it come to its minimum value at the optimum rotation speed of 150 (rpm). The curve of the forming total load attempted to arises again with any increase in the rotational speed. This conclusion can be found under burnishing load 20, 25 and 30 (KN). It can be also found that in different burnishing load the axial feed 0.3 (mm/rev) has the lowest value compared with different axial feed.

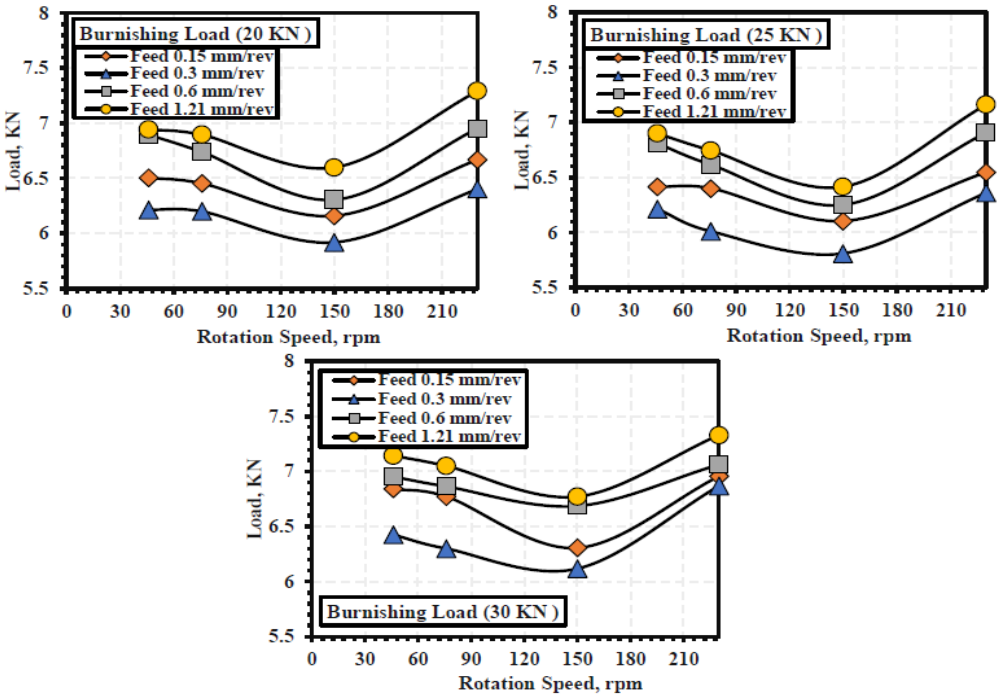


Figure 6: The Relationships between Maximum Forming Load and Rotation Speed with different Axial Feeds.

3.1.3. Effects of the Burnishing Load

The relationships between the burnishing load and the load required for the combined process are shown in **Figure 7**. It can be concluded from **Figure 7** that, the increase in the burnishing load decreases the process load till 25 KN burnishing load, then any increase in the burnishing load above 25 kN increases the process load and this is mainly due to the increased plastic deformation with high burnishing loads.

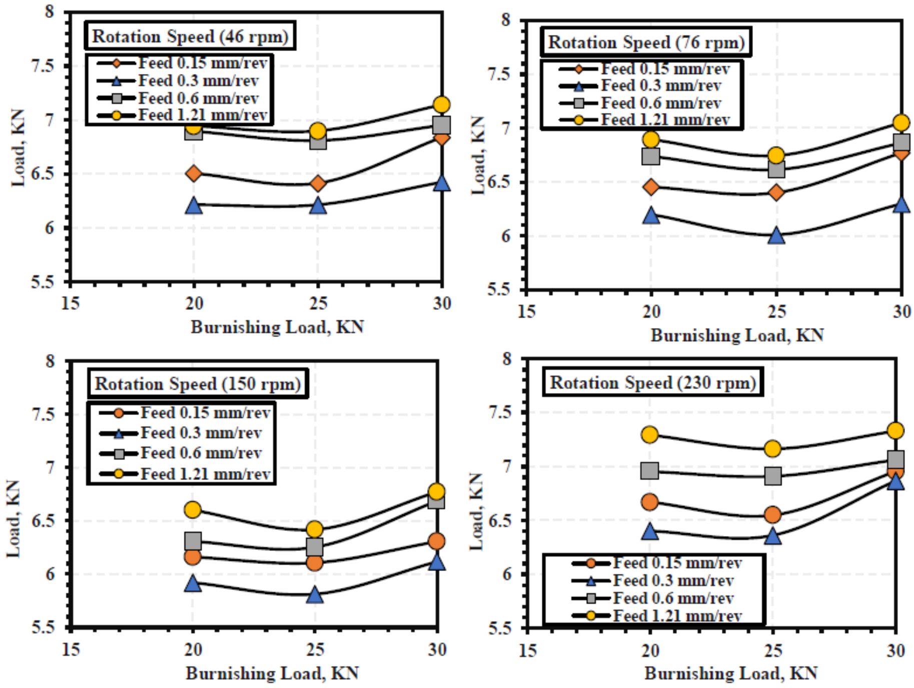


Figure 7: The Relationships between Maximum Forming Load and Burnishing Load under different Axial Feeds.

3.2. The Effect on Hardness

3.2.1. Effects of the Axial Feed

Figure 8 shows the influence of the axial feed on hardness for various rotation speeds. It is obvious from **Figure 8** that the hardness decreases with the increase in axial feed. This due to the increase of the space between the successive traces of the burnishing balls. because of that the total repeated deformation effect on the surface of the part. This will cause a decrease in products hardness.

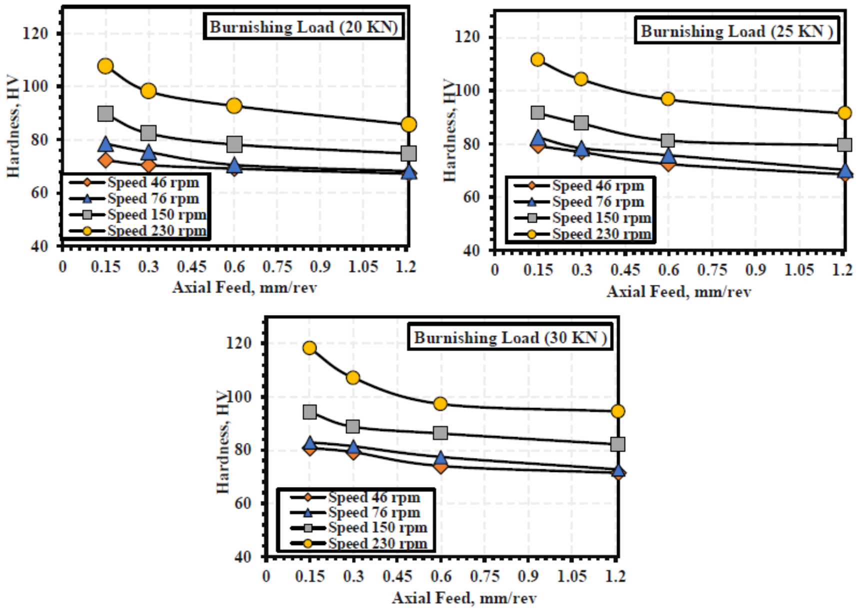


Figure 8: The Relationships between Hardness and Axial Feed under different Rotation Speeds.

3.2.2. Effects of the Rotation Speed

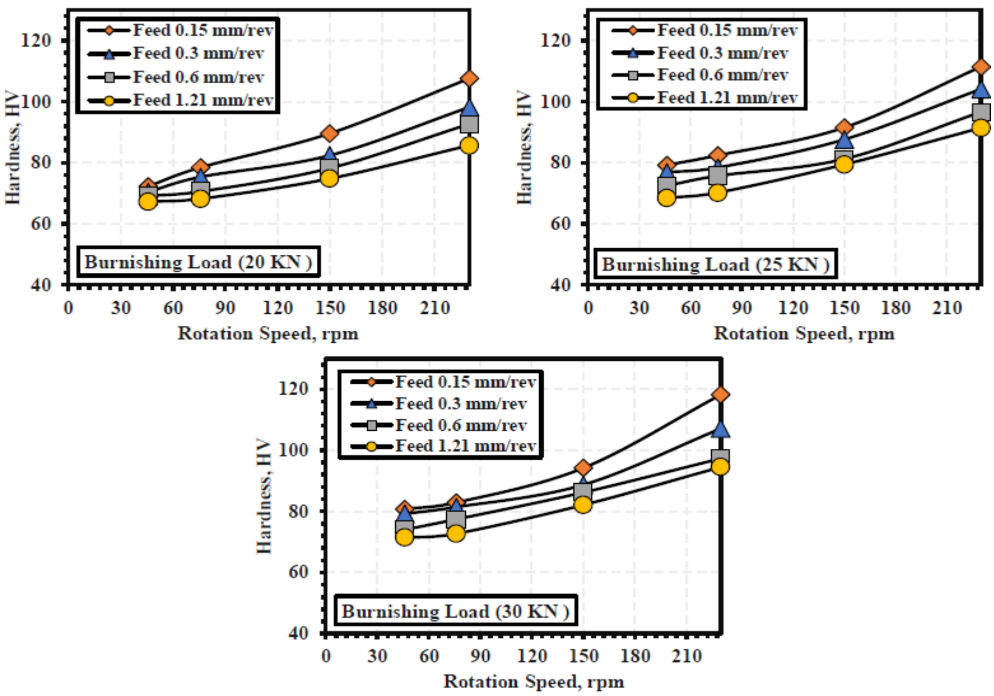


Figure 9: The Relationships between Hardness and Rotation Speed under Different Axial Feeds.

The relationships between the hardness and the rotation speed for the products of the proposed technique are shown in **Figure 9**. It can be concluded that the products surface hardness increases with the increase of the spindle speed. This relationship is probably described by an increase in work hardening due to high rotational speeds.

3.2.3. Effects of the Burnishing Load

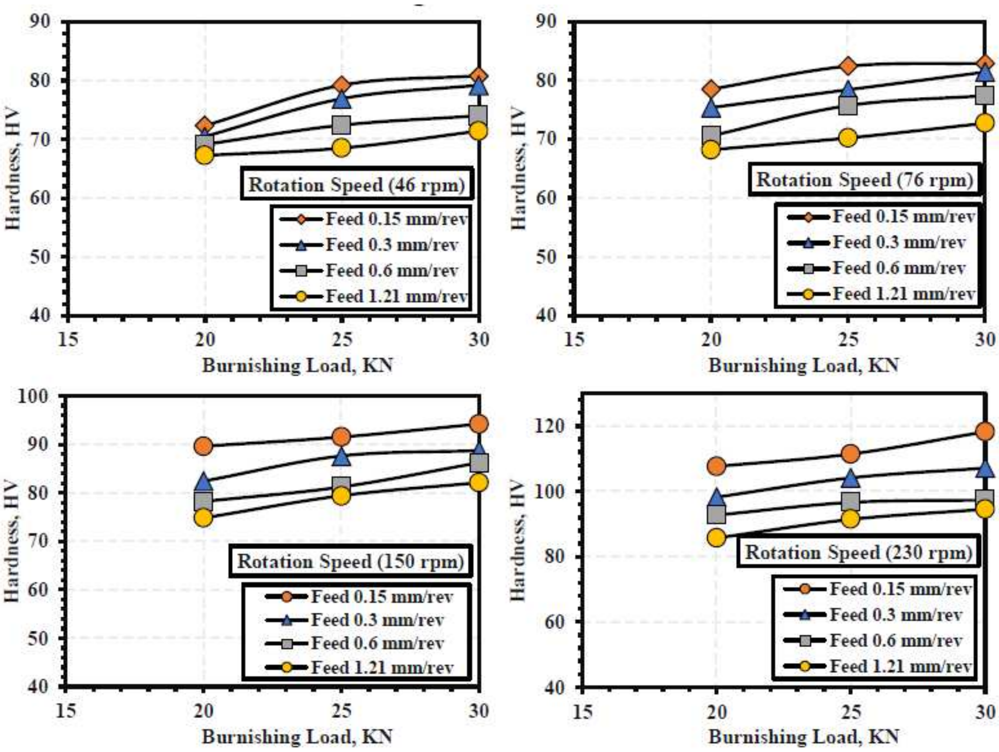


Figure 10: The Relationships between Hardness and Burnishing Load under different Axial Feeds.

The influence of burnishing Load on hardness is shown in **Figure 10**. The hardness of the workpiece increases with the increase in burnishing load. This is due to the increase in pressure submitted by the burnishing ball on the products surface.

As vertical burnishing load increases the behavior of the plastic deformation and the internal compressive residual stresses increases. This led to the increase in hardness.

3.3. The Effect on Surface Roughness

3.3.1. Effects of the Axial Feed

Figure 11 illustrates the influence of axial feed on surface roughness for various rotational speeds. It can be concluded that the increase of feed rate enhance the surface roughness to a lowest value, then starts to increase under given working parameters. This relation is probably explained by the space between the successive traces which is tiny when the feed rate is low. As the burnishing ball moves along the spun part, it will create a repeated deformation activity on the surface of the workpiece. When the axial feed is elevated, the space between the successive burnishing marks will be big, which will increase in the surface roughness of spun part.

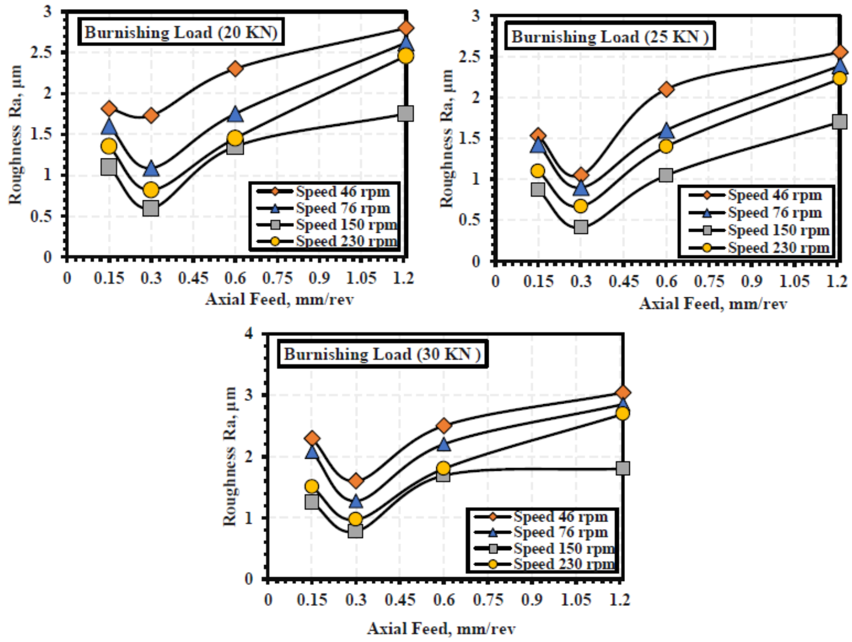


Figure 11: The Relationships between Surface Roughness and Axial Feed under different Rotation Speeds.

3.3.2. Effects of the Rotation Speed

Figure 12 Shows that the surface roughness improves with the increase in the rotational speed until it reaching a lowest level at 150 rpm. It starts to rise when factors like vibration of the combined tool which is obviously observed by the naked eye, which increases the chance of the burnishing ball-workpiece interface.

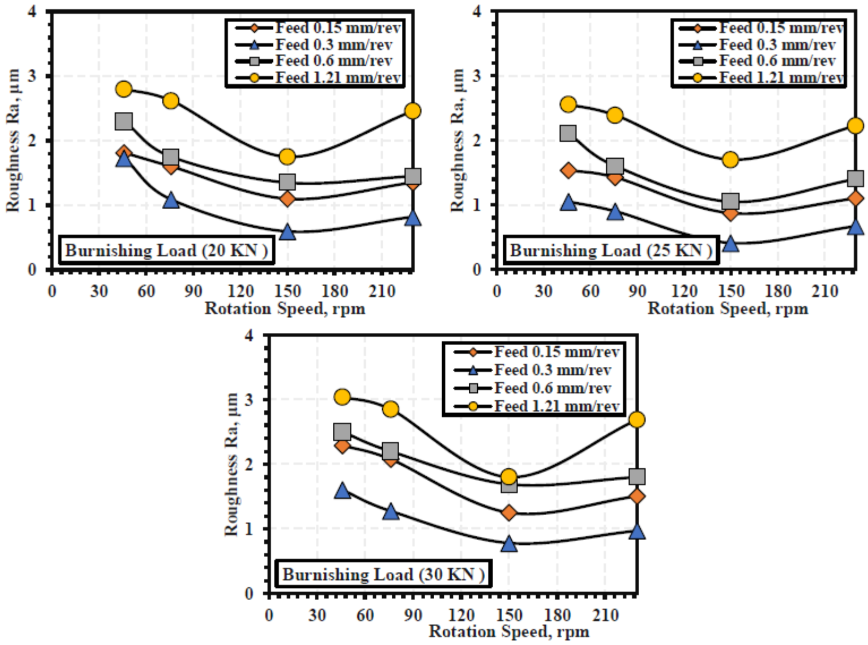


Figure 12: The Relationships between Surface Roughness and Rotation Speed under Different Axial Feeds.

3.3.3. Effects of the Burnishing Load

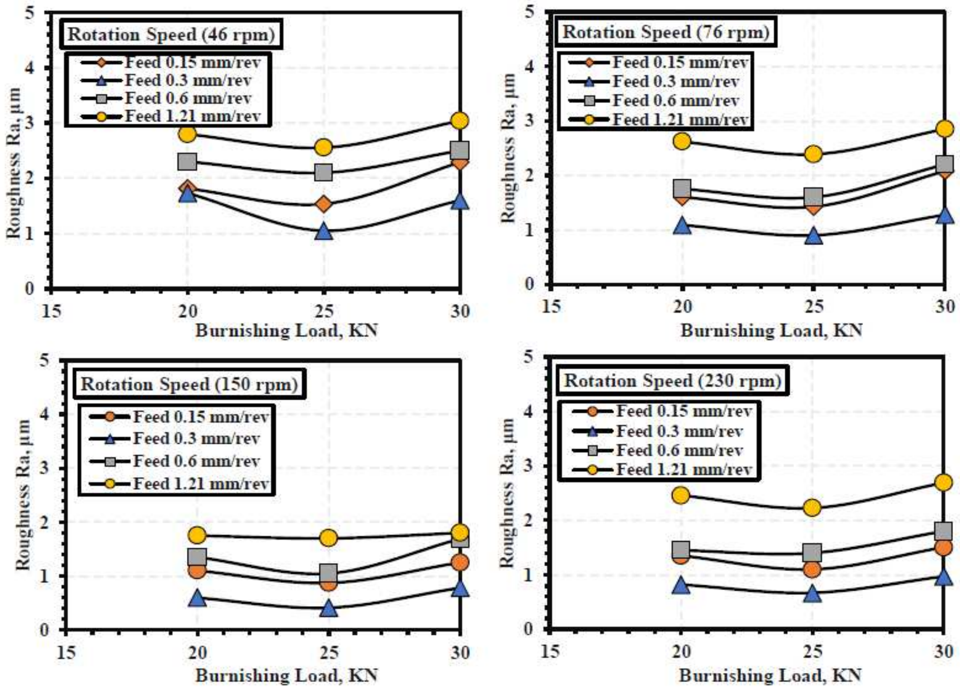


Figure 13: The relationships between Surface Roughness and Burnishing Load under different Axial Feeds.

Figure 13 describes the relationships between surface roughness and burnishing load under different axial feeds. It was observed that the surface roughness improves with the increase in burnishing load to a lowest level. Then the surface roughness tends to rise with increase in the load of burnishing. When burnishing load are elevated, the bile-up of the product metal in front of the burnishing ball extend in size, and the area of plastic deformation extends. When this plastic deformation is repeated, as the burnishing ball travels over the surface of the spun item, some defect of the product surface is expected, which will make an increase in surface roughness.

3.4. Effect of Distances between Shear Balls and Burnishing Balls on the Process

3.4.1. Effect on Maximum Total Load

The distance between the first ball and the rollers was set to its minimum value of 10 mm. This distance cannot be decreased furthermore than 10 mm because any decrease in this distance leads to the ball housing contacting the blank before the rollers. This distance is mentioned here as zero distance. Then, distance between first shear ball and second shear balls (D_{SB}) were tested. This distance will be increased to be 1, 2, and 3; which means 10, 11, 12, and 13mm between the first ball and the second ball of shear balls. The distance between the second ball of shear and the first burnishing ball was set to its minimum value of 5 mm. This distance is mentioned here as zero distance. then, the second distance (D_{BB}) between the first and the second burnishing ball started with zero mm then increased to 1, 2, and 3 mm. The influence of these distances on the process load is shown in **Figure 14**.

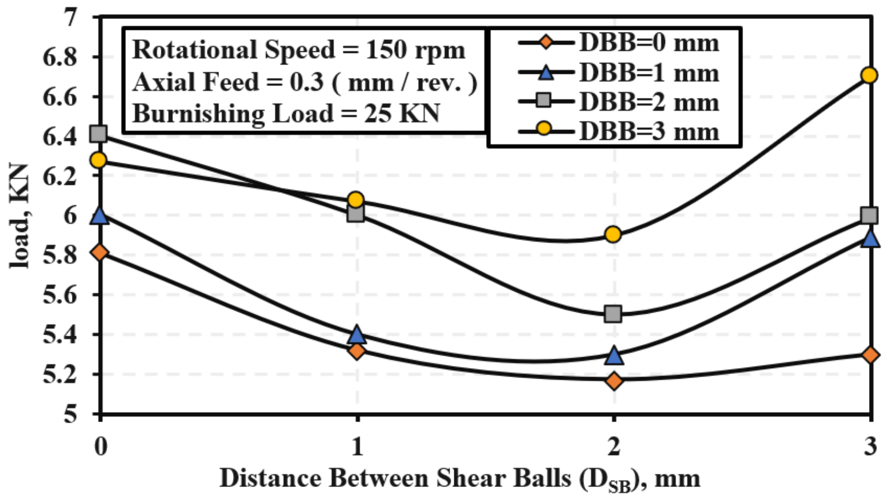


Figure 14: The Relationships between Maximum Forming Load and distances between Shear Balls under Burnishing Balls Distances.

As can be determined from **Figure 14** that any increase in D_{BB} increases the process load. This can be attributed to any increase of this distance increases the resultant force in radial direction. This led to increase of total maximum forming load. It can be also observed that, the forming load decreases with an increase of D_{SB} until 2 mm. Then any increase in this distance increase the process load. This relationship is probably described by interference between the two balls beside that the reduction in thickness is divided between the two balls which decreases the load. After the optimum distance of 2 mm between the two balls; the increase in distance increases the load and this is due to the increase in the strain hardening.

3.4.2. Effect on Hardness

The effect of distances D_{SB} and D_{BB} on the product hardness is represented at **Figure 15**. The hardness of the products is increased by any increase of these distances because the distances between the balls (D_{SB} and D_{BB}) increases the repeated plastic deformation. This led to increase in hardness of workpiece.

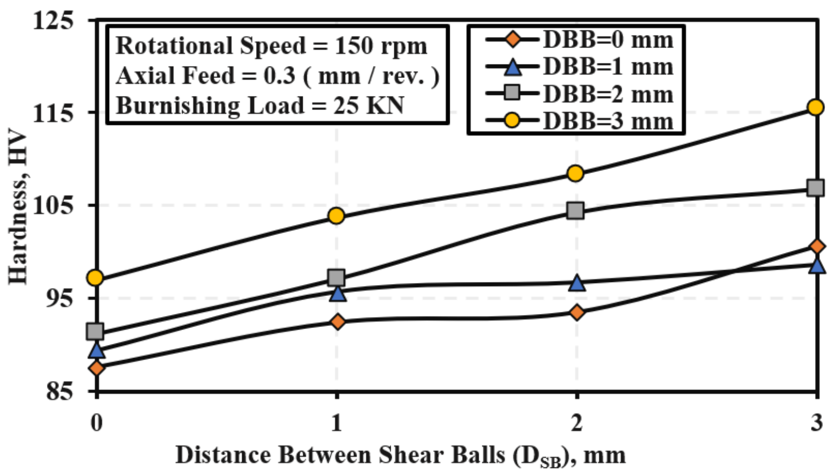


Figure 15: The Relationships between Hardness and Distances between Shear Balls under Burnishing Balls Distances.

3.4.3. The Effect on Surface Roughness

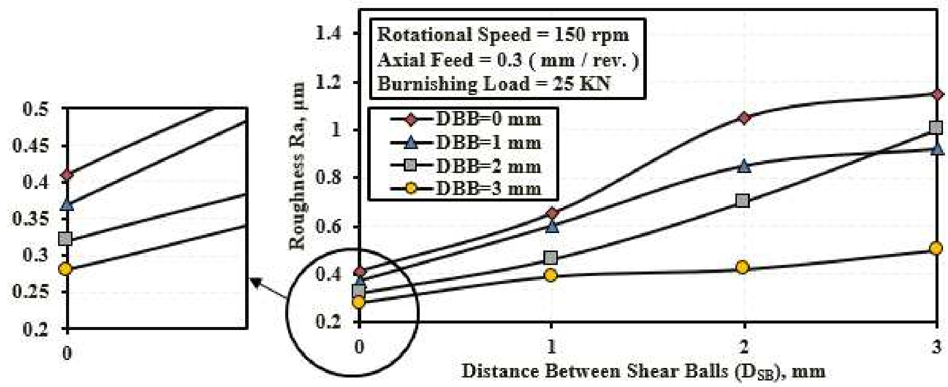


Figure 16: The Relationships between Surface Roughness and distances between Shear Balls under Burnishing Balls Distances.

The effect of distances D_{SB} and D_{BB} on the surface roughness is observed in **Figure 16.** The increase in the D_{BB} will increase of number of tool pass along the workpieces this give more opportunity for the highest peaks and lowest valleys of the workpiece to be polished. These effects will enhance the surface roughness. in addition, any increases of (D_{SB}) led to increase in surface roughness. This is due to increase of vibration in combined tool.

4. PHOTOGRAPH FOR THE SPECIMENS

Figure 17: Photograph of Successful Products

Figure 17 illustrates the photograph of some successful cups that produced by the proposed new technique.

Figure 18: Photograph for Unsuccessful Products.

Figure 18 shows the photograph of unsuccessful product. The defective products can be attributed to the high axial feed and disorder of toning in tool of the proposed technique (specimen 1 and 2). However, the defect observed in specimen 3 is probably explained by high burnishing load. Also, specimen 4, did not succeed because of high rotation speed. The tearing defect in specimen 5 can be explained by intense penetration of shear balls due to increase of vibration.

5. CONCLUSIONS

Under the conditions examined in the experimental work explained above, the following conclusions can be found:

- The combined new tool which has been designed and manufactured to perform three different processes (conventional spinning, shear spinning and burnishing process) is successful.

- The optimum condition for forming load and surface roughness occurred at rotation speed at 150 rpm, axial feed 0.3 mm/rev and burnishing load 25 KN.
- The surface hardness decreases with an increase in axial feed rate, while the hardness improves with an increase in load of burnishing balls and rotation speed.
- When distance between the shear balls increases the forming load decrease until it reaches its lowest level at 2 mm. Hardness and surface roughness increases by increasing the distance between shear balls.
- Hardness and forming load increase with an increase of space between burnishing balls. However, the surface roughness improves with an increase of burnishing balls distance.

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AUTHORS PROFILE

Karim Mohammed Atia received the B.Sc. degree with grade distinction with honour’s degree in 2013, and the M.Sc. degree 2017, both in Mechanical Engineering, from Minia University, Minia, Egypt. He is working toward the Ph.D. degree in Mechanical Engineering. His current research interest’s material forming.

S. Z. El-Abdenb received the B.Sc. degree in Mechanical engineering in 1986, the M.Sc. degree in 1993, all from Minia University, Egypt and the Ph.D. degree in 1999 Joint supervision between Minia University and Chemnitz University in

Germany. He is an Assistant Professor of production engineering and mechanical design Department, faculty of Engineering, Mina University, Egypt. His current research interest's material forming.

M. N. El-Sheikh received the B.Sc. degree from the Department of Production Engineering and Design, Faculty of Engineering, El-Minia University in 1975, the M.Sc. degree in 1982, all from Minia University, Egypt and the Ph.D. degree in 1987 From the (FPM) (Fertigungsprozess und Fertigungsmittel) , Technical University Karl - Marx - Stadt (Chemnitz) Germany. He is a Professor of Production Engineering, faculty of Engineering, Mina University, Egypt from 1999.

W. W. Marzouk received the B.Sc. degree in Mechanical engineering in 1973, the M.Sc. degree in 1982, all from Minia University, Egypt and the Ph.D. degree in 1987 in Poland. He is a Professor of production engineering and mechanical design Department from 1999, faculty of Engineering, Mina University, Egypt.